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APPLICATION

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ELECTRICAL COUPLING OF SUBSTRATES BY CONDUCTIVE BUTTONS

Background of the Invention

1. Technical Field

The present invention discloses a method and structure for electrically joining two substrates.

2. Related Art

FIG. 1 depicts a top view of a substrate **10** with a two-dimensional array of electrically conductive pads **12** (e.g., gold or gold-plated pads) on a surface of the substrate **10**, in accordance with the related art. The substrate **10** is an electrical substrate such as, *inter alia*, a printed wiring board or an electronic module (e.g., a module of a chip carrier with one or more attached semiconductor chips).

FIG. 2 depicts a cross-sectional view of an electrical structure **13** comprising substrates **14** and **18**, each such substrate being of the type shown in FIG. 1. As an example, the substrate **18** may include a printed wiring board and the substrate **14** may include an electronic module. The substrate **14** has electrically conductive pads **16**, and the substrate **18** has electrically conductive pads **20**. A conductive coupler **22** permanently electrically couples the substrate **14** to the substrate **18**. The conductive coupler **22** may be, *inter alia*, a solder ball, a solder column, etc.

A problem with the related art of FIG. 2 is that electrical structure **13** is vulnerable to

solder fatigue and failure at a contact surface **17** between the conductive pad **16** and the conductive coupler **22**, or at a contact surface **21** between the conductive pad **20** and the conductive coupler **22**. For example, the failure could result from thermal strain on the conductive coupler **22** introduced during temperature transients, said thermal strain resulting from differential coefficient of thermal expansion (CTE) between the substrate **14** and the conductive coupler **22**, between the substrate **18** and the conductive coupler **22**, between the substrate **14** and the substrate **18**, etc. Accordingly, there is a need for a method and structure that reduces the probability of such failure.

Another problem with the related art of FIG. 2 is that the electrical structure **13** cannot be easily repaired or upgraded in the field. Accordingly, there is a need for a method and structure that facilitates repairing or upgrading the electrical structure **13** in the field.

Summary of the Invention

The present invention provides an electrical structure comprising a conductive button, said conductive button including:

a dielectric core; and

a conductive wiring helically wound circumferentially around the dielectric core, wherein the conductive wiring terminates in at least two end contacts at a first end of the conductive button, and wherein the conductive wiring terminates in at least two end contacts at a second end of the conductive button.

The present invention provides a method for forming an electrical structure; comprising:

providing a dielectric core;

helically winding a conductive wiring circumferentially around the dielectric core; and

cutting, normal to an axis of the dielectric core, through the conductive wiring and through the dielectric core, at two locations along the axis, leaving a conductive button between the two location as having a first end and a second end, wherein the conductive wiring terminates in at least two end contacts at the first end, and wherein the conductive wiring terminates in at least two end contacts at the second end.

The present invention reduces the probability of failure of the electrical coupling between two substrates of an electrical structure. Additionally, the present invention facilitates repairing or upgrading of the electrical structure.

Brief Description of the Drawings

FIG. 1 depicts a top view of a substrate with an array of conductive pads on a surface of the substrate, in accordance with the related art.

FIG. 2 depicts a cross-sectional view of an electrical structure comprising two substrates electrically and mechanically joined at corresponding conductive pads by a conductive button, in accordance with the related art.

FIG. 3 depicts a cross-sectional view of two substrates electrically and mechanically coupled at corresponding conductive pads by conductive buttons, in accordance with embodiments of the present invention.

FIG. 4 depicts a perspective view of a dielectric core, in accordance with embodiments of

the present invention.

FIG. 5 is depicts conductive wiring helically wound around the dielectric core of FIG. 4.

FIG. 6 depicts the helical wiring of FIG. 5 as braided.

FIG. 7 depicts the helical wiring of FIG. 5 as served.

FIG. 8 depicts an outer dielectric jacket extruded onto the helically wired dielectric core of FIG. 5, thus forming a conductive rod.

FIG. 9 depicts a cross-sectional view of the dielectric jacket extrusion process of FIG. 8.

FIG. 10 depicts the conductive rod of FIG 8 after being inserted into a dielectric place holder.

FIG. 11 depicts FIG. 10 after the conductive rod and similar conductive rods have been axially cut, leaving conductive buttons in the dielectric place holder.

FIG. 12 depicts a cross-sectional view of end contacts of a conductive button, said end contacts created by mechanical cutting of a conductive rod from which the conductive button was formed, in accordance with embodiments of the present invention.

FIG. 13 depicts FIG. 3 with conductive buttons being soldered to one of the two substrates, in accordance with embodiments of the present invention.

FIG. 14 depicts FIG. 13 after conductive buttons have been soldered to the other of the two substrates, in accordance with embodiments of the present invention.

Detailed Description of the Invention

FIG. 3 depicts a cross-sectional view of substrates **32** and **34** electrically and

mechanically joined at corresponding conductive pads **33** and **35**, respectively, by conductive buttons **38**, in accordance with embodiments of the present invention. The word, "conductive," (and variants thereof such as "conductively") herein means "electrically conductive" unless otherwise noted. The conductive pads **33** and the conductive pads **35** each constitute a two-dimensional array of electrically conductive pads (e.g., gold or gold-plated pads). The substrate **34** may include, *inter alia*, a printed wiring board (PWB). The substrate **32** may include, *inter alia*, an electronic module such as a chip carrier with one or more attached semiconductor chips.

The conductive button **38** electrically couples the substrate **32** at the pad **33** to the substrate **34** at the pad **35**. Each conductive button **38** comprises a dielectric core **40**, a conductive wiring **42** helically wound around the dielectric core **40**, and an outer dielectric jacket **44** around the conductive wiring **42**. The conductive wiring **42** terminates in the end contacts **47** at an end **41** of the button **38**, where the end contacts **47** mechanically and electrically contact the pad 35. The conductive wiring **42** also terminates in the end contacts **48** at an end **43** of the button **38**, where the end contacts **48** mechanically and electrically contact the pad **33**. As a result, the substrate **32** is conductively coupled to the substrate **34** by the following conductive path: pad **33**, end contacts **48**, conductive wiring **42**, end contacts **47**, and pad **35**.

The aforementioned mechanically and electrically contacting of the end contacts **47** and **48** to the pads **35** and **33**, respectively, is accomplished by application of a compressive force **46** (e.g., clamping) on the electrical structure **30**. The compressive force **46** is transmitted to the pads **33** and **35** where the transmitted force on the pads **33** and **35** is directed toward the button **38**. A dielectric place holder **36** holds the buttons **38** in place. The dielectric place holder **36** is

electrically insulative. Since the force **46** is capable of being released or removed, the electrical structure of FIG. 3 facilitates repairing or upgrading in the field because substrates **32** and **34** can be readily decoupled by release or removal of the force **46**.

In an embodiment of the present invention, the dielectric core **40**, the dielectric jacket **44**, and the conductive wiring **42** are each sufficiently compressible so as to accommodate up to about 8 mils of composite variability that includes a planarity of a surface **25** of the substrate **32** and a planarity of a surface **26** of the substrate **34** which is opposite the surface **25** of the substrate **32**. For example, if the substrate **32** is an electronic module then the variability in planarity of the surface **25** may be in a range of about ½ mil to about 6 mils, and if the substrate **34** is a printed wiring board then the variability in planarity of the surface **26** may be in a range of about ½ mil to about 2 mils. Thus, the dielectric core **40**, the dielectric jacket **44**, and the conductive wiring **42** are each compressible in a direction that is parallel to an axis of the button (i.e., in a direction **54** or **55**).

The dielectric material of the dielectric core **40** or the dielectric jacket **44** may be an elastomer, and a compliance of an elastomer is related to material hardness on the Shore scale. Accordingly, the dielectric material of the dielectric core **40** or of the dielectric jacket **44** may, in particular embodiments of the present invention, have a hardness between about 37A and about 56D on the Shore scale.

Representative materials for the dielectric core **40** or the dielectric jacket **44** include: polytetrafluoroethylene (PTFE), expanded polytetrafluoroethylene, Hylene® TPE 9300C (Dupont), Hytrel® 4069 (Dupont), Teflon® PFA 350 (Dupont), Pellethane® 2102 (Dow), GTPO

8202 GITTO Global (Dupont), GTPO 8102 GITTO Global (Dupont), FEP 100 (Dupont), Chemigum (Goodyear), Versaflex® OM 1040 (GLS Corp.), Dynaflex® G7702 (GLS Corp), Dynaflex® G7722 (GLS Corp.), Santoprene® 8271-55 (Advanced Elastomer Systems), Dyneon® FC 2120 3M 5100. The dielectric core **40** and the dielectric jacket **44** may include a same dielectric material or different dielectric materials. In embodiments of the present invention, the dielectric core **40** has a diameter between about 10 mils and about 20 mils.

Representative materials for the conductive wiring **42** include copper, copper alloys (e.g., BeCu, phosphor bronze), nickel, palladium, platinum, and gold. To reduce or eliminate corrosion, the end contacts **47** and **48** of the conductive wiring **42** may be coated with a noble metal such as, *inter alia*, gold. In embodiments of the present invention, the conductive wiring **42** has a diameter between about 1 mil and about 5 mils.

FIGS. 4-11 depict steps in a fabrication of a conductive button such as the conductive button **38** in FIG. 3.

FIG. 4 depicts a perspective view of a dielectric core **50**, in accordance with embodiments of the present invention. The dielectric core **50** includes a dielectric material such as the dielectric material of the dielectric core **40** described *supra* in conjunction with FIG. 3. The outer surface of the dielectric core **50** has grooves **51** oriented axially in the direction **54** or **55**, said directions **54** and **55** being parallel to the axis (or axial direction) of the dielectric core **50**. The grooves **51** accommodate any hyperelasticity of the dielectric core **50** (or of the dielectric jacket **59** in FIG. 8, described *infra*) by providing space for the dielectric material of the dielectric core **50** to deform into. An alternative to the grooves **51** for accommodating

hyperelasticity of the dielectric core **50** (or of the dielectric jacket **59** in FIG. **8**) is an axial through hole in the direction **54** or **55** at a radial center **52** of the dielectric core **50**. The axial through hole may be created by forming the dielectric core **50** around a solid wire and subsequently removing the solid wire to form the through hole. The solid wire provides a stiffening member during formation of the dielectric core **50** and during placement of conductive helical wiring **53** and **56** (see FIG. 5 discussed *infra*). The solid wire may be removed before or after the dielectric core **50** is cut to length (see FIG. 10 and accompanying discussion *infra* relating to cutting conductive rod **60** which contains a dielectric core). The solid wire may be retained within the dielectric core to serve as an additional electrical path between two opposing electrically conductive pads (e.g., pads **33** and **35** of FIG. 3). Another alternative for accommodating the hyperelasticity includes having the dielectric core **50** of FIG. 4 include a foamed material having internal voids or bubbles into which the dielectric material of the dielectric core **50** may deform.

The dielectric material of the dielectric core **50** and dielectric jacket **59** (see FIG. 8) may have other properties, such as: shrinking in length (i.e., in the direction **54** or **55**) during exposure to heat or ultraviolet radiation; or bonding together during exposure to heat or ultraviolet radiation.

FIG. 5 depicts conductive wiring **49** helically wound around the dielectric core **50** of FIG. 4. The conductive wiring **49** includes conductive wiring **53** helically wound in a clockwise direction and conductive wiring **56** helically wound in a counterclockwise direction. The scope of the present invention includes conductive wirings **53** and **56** both present, and alternatively

either but not both of conductive wirings **53** and **56** present. If the conductive wirings **53** and **56** are both present then the conductive wirings **53** and **56** may be helically would in a braided manner, resulting in a braided conductive wiring **57** shown in FIG. 6. Also if the conductive wirings **53** and **56** are both present then the conductive wirings **53** and **56** may be helically would in a served (i.e., overlaid) manner, resulting in a served conductive wiring **58** shown in FIG. 7.

FIG. 5 shows a helical angle θ of the conductive wiring **53** relative to the axis of the dielectric core **50** (i.e., relative to the direction **54**). For some embodiments of the present invention, θ is between about 30 and 60 degrees.

FIG. 8 depicts an outer dielectric jacket **59** extruded onto the helically wired dielectric core **50** of FIG. 5, thus forming a conductive rod **60**. The conductive rod **60** comprises the outer dielectric jacket **59** on the helically wired dielectric core **50**.

FIG. 9 depicts a cross-sectional view of the dielectric jacket extrusion process of FIG. 8. In FIG. 9, the dielectric core **50** with helically wound conductive wiring **49** is rolled on a spool **95**. The dielectric core **50** with helically wound conductive wiring **49** is shown being pulled by force **96** through extrusion die **97**. While the conductive core **50** is traveling through the extrusion die **97**, the outer dielectric jacket **59** is formed from melted dielectric jacket material **98** flowing through extrusion die **97** as is known in the cable making art.

FIG. 10 depicts the conductive rod **60** of FIG 8 after being inserted into a dielectric place holder **70** which serves to hold the conductive rod **60** in place while being subsequently cut up into the conductive buttons of the present invention and while the conductive buttons are positioned so as to mechanically and electrically couple two substrates (e.g., the substrates **32**

and **34** of FIG. 3). The conductive rod **60** is fitted into a hole **72** of the place holder **70** by any suitable method such as, *inter alia*, friction fitting, molding, and glueing.

FIG. 10 shows cutting of the conductive rod **60** at the locations **68** and **69**. The cutting may be accomplished by use of a laser (i.e., "lasering") or by any other suitable method. For example, another suitable method of cutting is mechanical cutting such as with a shearing or an electrical discharge machining (EDM) process. The cutting may be at an angle ϕ with respect to the direction **55**, such that ϕ in a range of $0 < \phi \leq 90$ degrees. FIG. 10 shows conductive buttons **73**, **74**, and **75** after such buttons have been formed by the aforementioned cutting. In embodiments of the present invention, each conductive button may have, *inter alia*, a height that includes about 3 to 5 mils above a top surface **62** of the place holder **70** and about 3 to 5 mils below a bottom surface **64** of the place holder **70** for a total height that is about 6 to 10 mils greater than a thickness "t" of the place holder **70** as shown in FIG. 10.

FIG. 11 depicts the place holder **70** of FIG. 10 after the conductive rod **60** of FIG. 10 and similar conductive rods have been axially cut, leaving conductive buttons **73-81** in the dielectric place holder **70**. FIG. 11 shows concentric through holes that have been formed in each conductive button (e.g., through hole **84** in the conductive button **74**). Such through holes in the conductive buttons **73-81** in FIG. 11 exemplify the discussion *supra*, in conjunction with FIG. 4, of forming an axial through hole in the direction **54** or **55** at a radial center **52** of the dielectric core **50**.

The conductive buttons **73-81** in FIG. 11 were formed after the conductive rod **60** (and similar conductive rods) were fitted within the place holder **70** of FIG. 10 followed by cutting the

conductive rod **60** (and the similar conductive rods) into the conductive buttons **73-81**. Alternatively, the conductive buttons **73-81** could have been formed by first cutting the conductive rod **60** (and the similar conductive rods) into the conductive buttons **73-81** without use of the place holder **70**, followed by fitting the conductive buttons **73-81** into the place holder **70**.

In FIG. 11, the end contacts formed by the method of the present invention are "raised" relative to the dielectric core and dielectric jacket. For example, the end contact **86** of the conductive button **75** is raised relative to the dielectric core and the dielectric jacket of the conductive button **75**. The end contacts, as raised, are also illustrated in FIG. 3, wherein the end contacts **47** are raised (i.e., protrude in the direction **54**) relative to both the dielectric core **40** and the dielectric jacket **44** of the conductive button **38**, and wherein the end contacts **48** are raised (i.e., protrude in the direction **55**) relative to both the dielectric core **40** and the dielectric jacket **44** of the conductive button **38**. The aforementioned raising or protrusion of the end contacts **47** and **48** enables the end contacts **47** and **48** to mechanically and electrically contact conductive structure (i.e., enabling the end contacts **47** and **48** to mechanically and electrically contact the conductive pads **35** and **33**, respectively, of FIG. 3). The aforementioned lasering (i.e., laser cutting) of the conductive rod **60** and similar conductive rods (see FIG. 10) facilitates the raising or protrusion of the end contacts **47** and **48** of FIG. 3, because the laser beam generally cuts a wider path (i.e., wider in the direction **54** or **55** - see FIG. 10) through the dielectric core **50** and dielectric jacket **59** than through the helically wound conductive wiring.

The end contacts of the conductive buttons **73-81** in FIG. 11 may have various shapes

which depend on the method used to cut the conductive rods to form the conductive buttons. For example, if a laser is used to do the cutting then the end contacts typically have a non-planar shape due to the heating effect caused by interaction of the laser radiation with the conductive wiring. As an example, the end contacts **47** and **48** in FIG. 3 have a surface curvature (e.g., spherical or elliptical) with an associated surface concavity toward the conductive button **38**. A spherical or similar shape for the end contacts is desirable if the end contacts are to be mated with a substrate conductive pad that is susceptible to being damaged by contact with sharp or pointed end contacts. For example, if the conductive pad is a flat, gold pad on a surface of an electronic module, the end contact should have a spherical or similar shape so that the resultant stress on the pad will be low enough so as not to damage the gold pad, but high enough to make good electrical contact with the gold pad.

If the cutting is done mechanically, however, the cutting introduces a mechanical shear and creates a chisel effect with a chisel angle that is related to the helical angle of the conductive wiring. As an example, FIG. 12 illustrates a cross-sectional view of a conductive button **88** having a dielectric core **89** and conductive wiring **90** helically wound circumferentially around the dielectric core **89**, and an outer dielectric jacket **92** around the conductive wiring **90**. The conductive wiring **90** has end contacts **91**, wherein the end contacts **91** have been generated by mechanical cutting such as with a shearing or EDM process. Due to the mechanical cutting, the end contacts **91** tend to have a chisel-like planar shape. Other shapes may be generated for the end contacts by varying the cutting method as well as the cutting details for a given cutting method. For example, the cutting device itself could be moved during the cutting process so as

to vary the cutting direction (e.g., cutting height) as the cutting is occurring. To illustrate the usefulness of the chisel-like shape, a solder-coated pad has a surface oxide that needs to be penetrated by the end contacts. If the conductive wiring is cut mechanically, the resultant end contact tends to be chisel-like and sharp enough to penetrate the surface oxide and lock into the solder surface so as to contact the conductive structure of the pad .

For a conductive rod having conductive wiring made of a non-noble metal or of a non-noble metal having a noble metal plating thereon, the end contact **86** (see FIG. 11) formed by cutting may be plated, after cutting, with a noble metal plating to provide corrosion resistance.

Another technique that affect the shape of other characteristics of an end contact is to cut the conductive rod (e.g., the conductive rod **60** of FIG. 10) at a node (i.e., intersection or point of crossing) of two wires of the conductive wiring, such as at a node **61** of the intersection of the conductive wiring **53** and **56** in FIG. 5. An end contact resulting from cutting the conductive rod at such a node, in comparison with an end contact not formed at such a node; would provide a larger end contact, would be stiffer, would common the two intersecting or crossing wires together, and would give a better metallurgical coupling (i.e., a mechanically stronger coupling) between the two wires. Note, however, that cutting through the two intersecting or crossing yields only one end contact instead of two end contacts.

The multiple (e.g., a plurality) of end contacts at each end of a conductive button provides conductive redundancy, so that if one or more end contacts should fail (e.g., become conductively decoupled from a substrate pad), then conductive coupling would nonetheless persist due to the conductive functionality of other end contacts that have not failed.

For example, a dielectric core of approximately 10 mils (i.e. 0.010 inches) having a circumference of approximately 31 mils can have 10 wires of 1 mil diameter in each helical direction with a spacing of approximately 3 mils. These wires can provide 10 to 20 end contacts depending how the end contacts are formed.(e.g., depending on how many of the end contacts are formed at nodes, as discussed *supra*).

Another feature of using the conductive buttons of the present invention to conductively couple two substrates is that the conductive buttons are less susceptible to thermal stress-induced failure than are solder interconnects (e.g., solder balls, solder columns, etc.) that conductively couple the two substrates. In particular, the conductive buttons facilitate more flexible substrate structures with a higher fatigue life than do solder interconnects, because the helically wound conductive wiring material (e.g., BeCu, beryllium, nickel, etc.) of the present invention is not as subject to as much shear as is solder in a solder interconnect. In particular, the helical winding does not give rise to a pure shear but rather to a bending stress, which results in a lower stress level in the wires. Thus, fatigue damage is accumulated at a slower rate per cycle inasmuch as the helical wiring pattern distributes the stresses in different directions relative to the axial direction (i.e., the direction **54** or **55** in FIG. 3).

As stated *supra*, the electrical structure of FIG. 3 facilitates repairing or upgrading in the field because substrates **32** and **34** can be readily decoupled by release or removal of the force **46**. This feature results from the fact that the conductive buttons **38** in FIG. 3 are not permanently attached to the pads **35** and **33** of the substrates **34** and **32**, respectively. Another embodiment of the present invention is to permanently attach the conductive buttons **38** to the pads **33** prior to

applying the force **46** in FIG. 3. Accordingly, FIG. 13 depicts FIG. 3 with end contacts **48** of conductive buttons **38** soldered to the pads **33** of the substrate **32** prior to application of the force **46**, in accordance with embodiments of the present invention. A solder interface **31** mechanically and conductively couples the end contacts **48** to the pads **33**. If the substrate **32** is an electronic module and the substrate **34** is a printed wiring board, then the solder interface **31** enables the collective unit of the substrate **32** (i.e., the electronic module) and the attached conductive button **38** to be repaired or removed in the field should the substrate **32** fail during field testing or during field operation. If the substrate **32** is a printed wiring board and the substrate **34** is an electronic module, then the solder interface **31** enables the substrate **32** (i.e., the electronic module) to be repaired or removed in the field should the substrate **32** fail during field testing or during field operation.

As an additional embodiment, FIG. 14 depicts FIG. 13 after end contacts **47** of conductive buttons **38** have been soldered to the pads **35** of the substrate **34**, in accordance with embodiments of the present invention. In FIG. 14, a solder interface **45** mechanically and conductively couples the end contacts **47** to the pads **35**. Note that the force **46** (see FIG. 13) is not present in FIG. 14, because the solder interfaces **31** and **45** cause the end contacts **48** and **47**, respectively, to be permanently attached (mechanically and conductively) to the pads **33** and **35**, respectively. As an example, the permanent solder connection between the end contacts **47** to the pads **35** may be effectuated after the electrical structure **30** has been successfully tested.

While embodiments of the present invention have been described herein for purposes of illustration, many modifications and changes will become apparent to those skilled in the art.

Accordingly, the appended claims are intended to encompass all such modifications and changes as fall within the true spirit and scope of this invention.